FET AMPLIFIERS AND SWITCHING CIRCUITS

Lecture 6

OVERVIEW

- JFET Amplifier Operation
- DC Analysis
- AC Analysis
- D-MOSFET Amplifier
- E-MOSFET Amplifier
- MOSFET Analog Switching
- MOSFET Digital Switching
- MOSFET in Power Switching

JFET AMPLIFIER OPERATION

- A *common-source* JFET Amplifier is one in which the AC input signal is applied to the gate and the AC output signal is taken from the drain.
- The source terminal is common to both the input and output signal.
- A common-source amplifier either has no source resistor or has a bypassed source resistor, so the source is connected to AC ground.

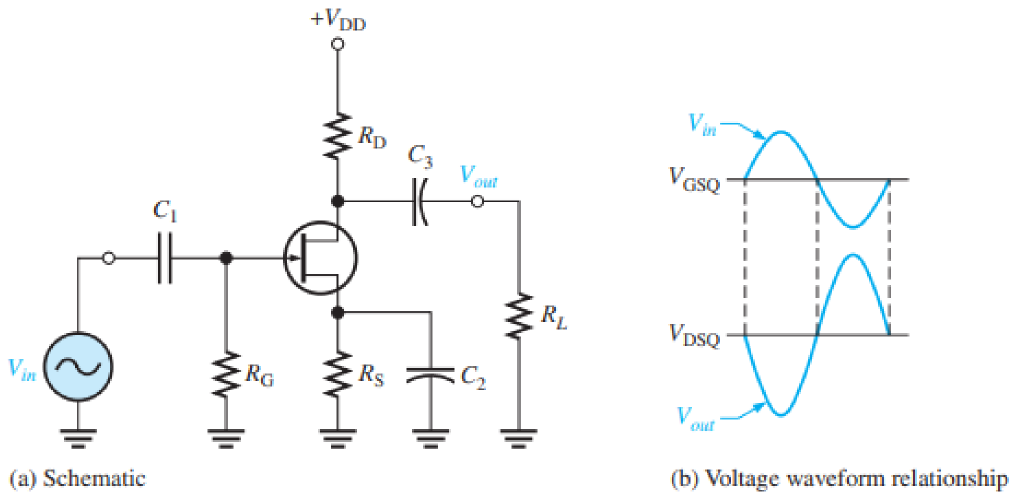
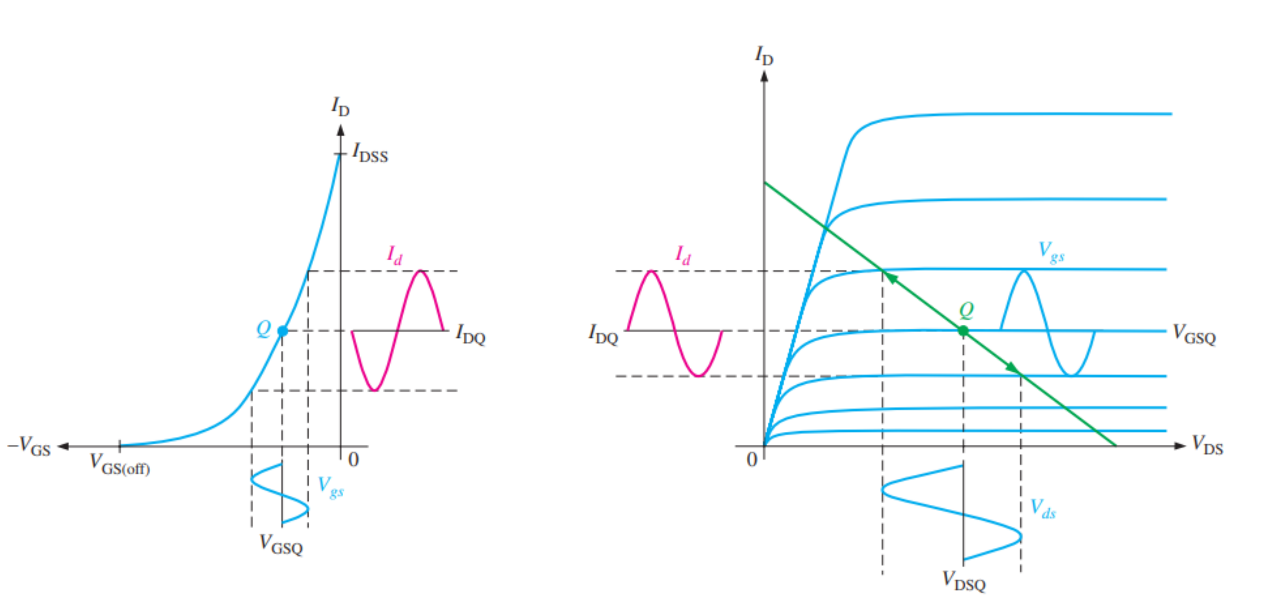


FIGURE 9–3

JFET common-source amplifier.

JFET AMPLIFIER. AC ANALYSIS

- The input signal voltage causes the gate-to-source voltage to swing above and below its **Q-point** value (V_{GSQ}), causing a corresponding swing in drain current.
- As the drain current increases, the voltage drop across R_D also increases, causing the drain voltage to decrease.
- The drain current swings above and below its **Q-point** value in phase with the gate-to-source voltage.
- The drain-to-source voltage swings above and below its **Q-point** value (V_{DSQ}) and is 180° out of phase with the gate-to-source voltage.



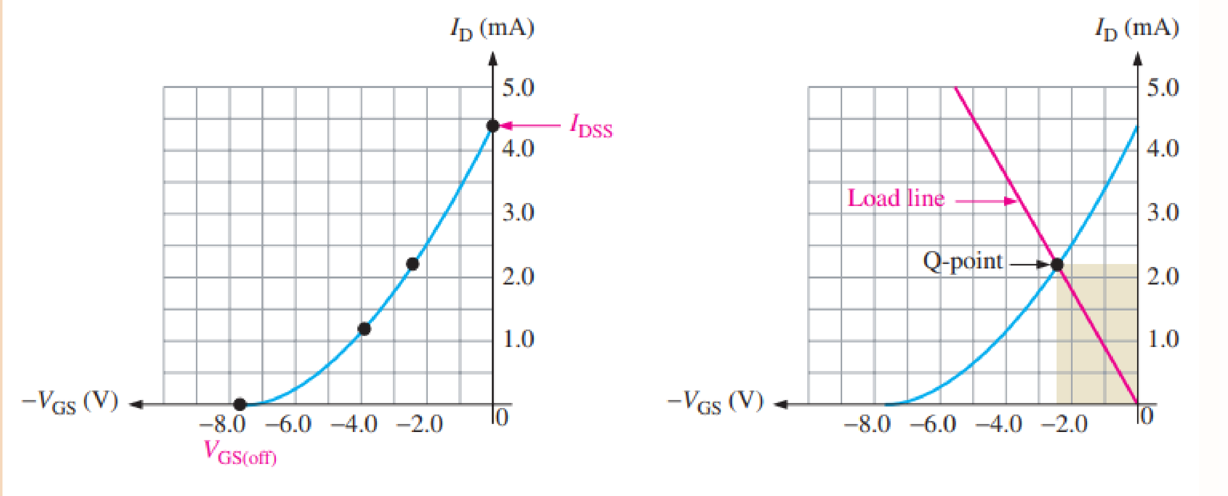
JFET AMPLIFIER. DC ANALYSIS

- I_D determines the **Q-point** for an amplifier and enables you to calculate V_D, so it is useful to determine its value. It can be found either graphically or mathematically:

$$I_D = I_{DSS}(1 - \frac{V_{GS}}{V_{GS(off)}})^2$$

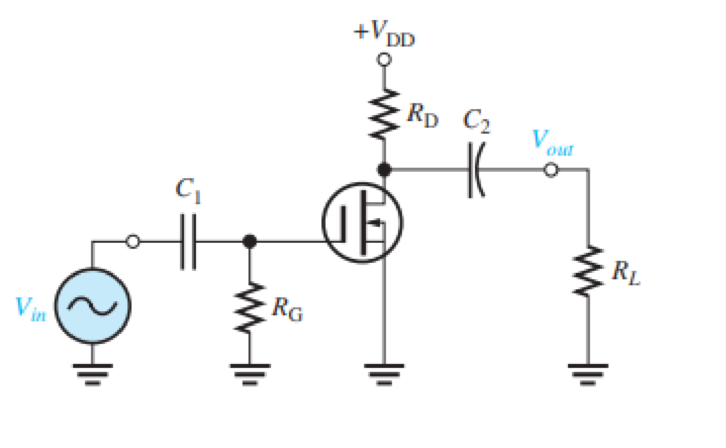
- The endpoints of the transconductance curve are at I_{DSS} and $V_{GS(off)}$.

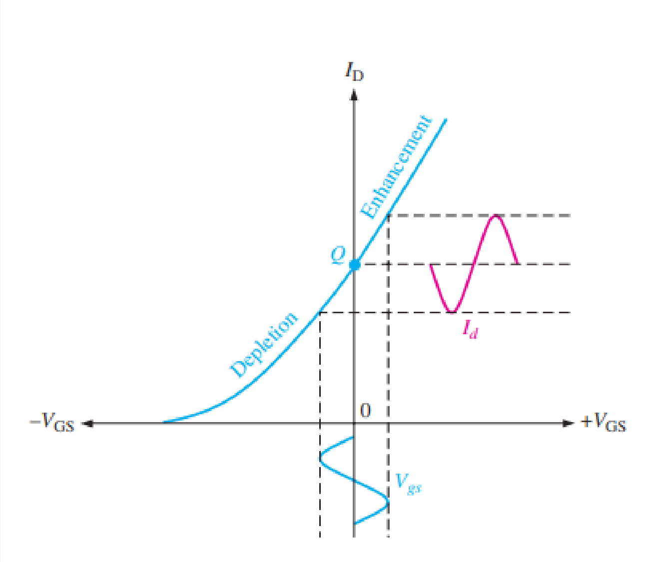
- A DC graphical solution is done by plotting the load line on the same plot and reading the values of V_{GS} and I_D at the intersection of these plots (**Q-point**)

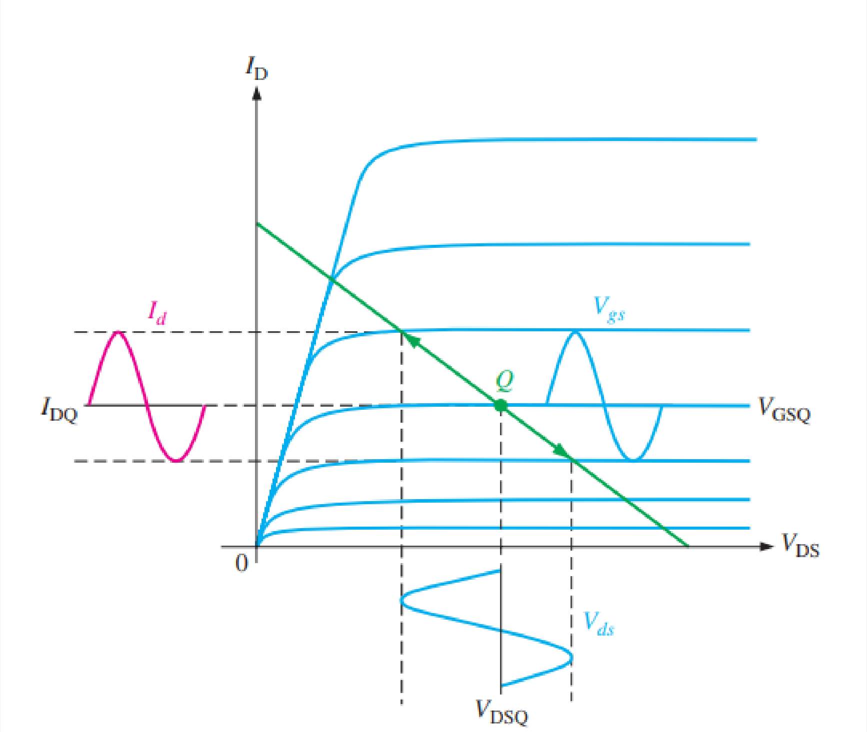


D-MOSFET AMPLIFIER

- The gate is at approximately 0 V DC and the source terminal is at ground, thus making $V_{GS} = 0\ V$
- The signal voltage causes V_{GS} to swing above and below its zero value, producing a swing in I_d.
- The negative swing in V_{GS} produces the depletion mode, and I_d decreases.
- The positive swing in V_{GS} produces the enhancement mode, and I_d increases.

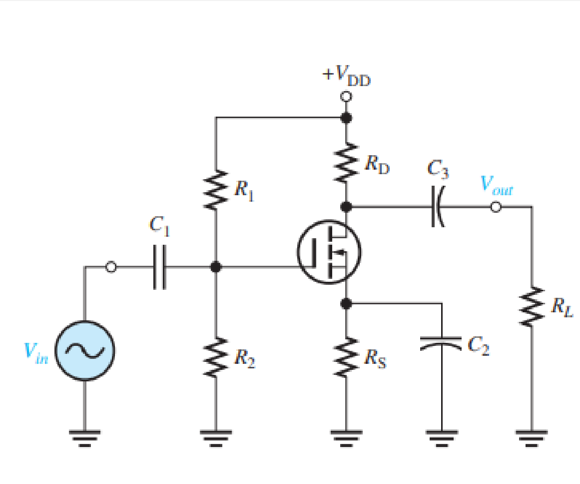


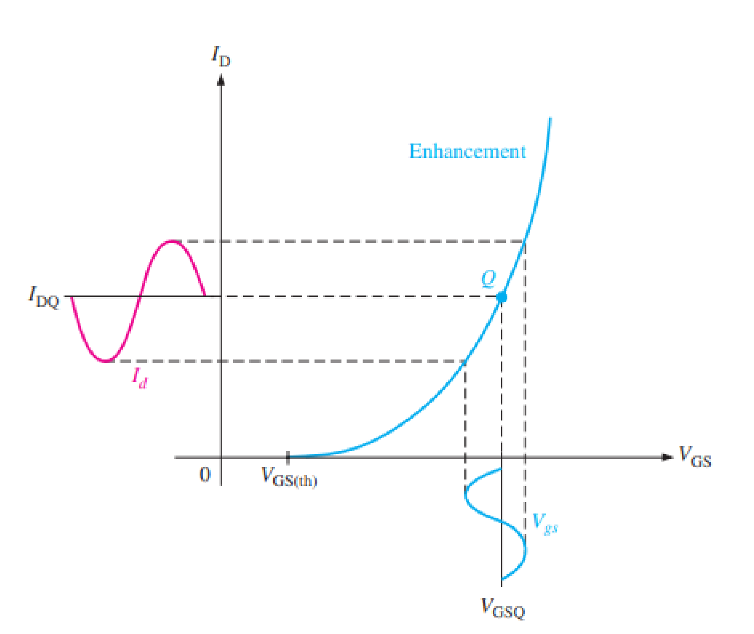


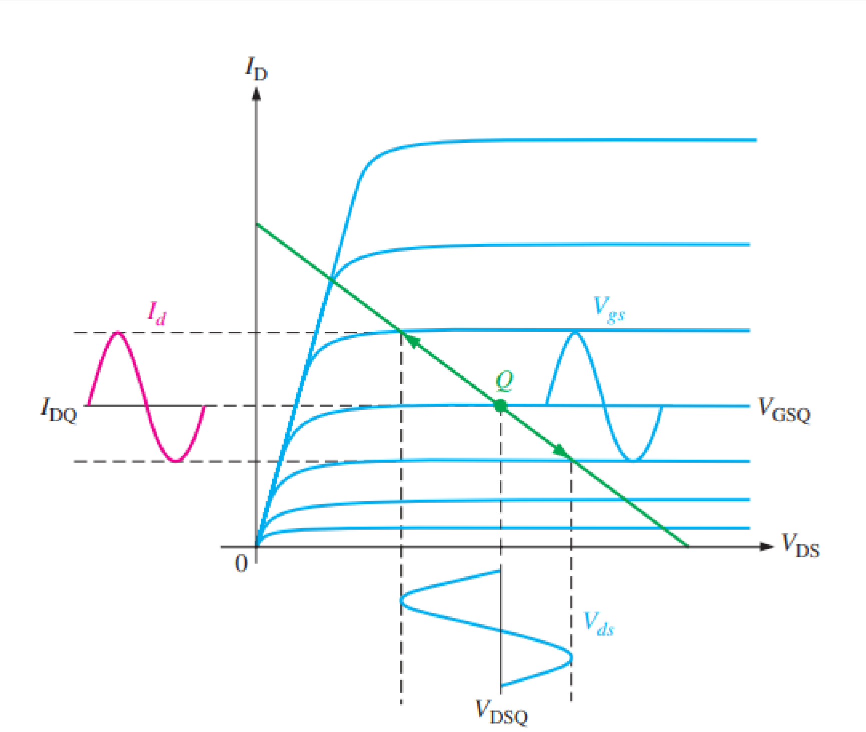


E-MOSFET AMPLIFIER

- The gate is biased with a positive voltage such that $V_{GS} > V_{GS(th)}$
- As with the JFET and D-MOSFET, the signal voltage produces a swing in V_{GS} above and below its Q-point value, V_{GSQ}. This causes a swing in I_d above and below its Q-point value, I_{DQ}.
- Operation is entirely in the enhancement mode.





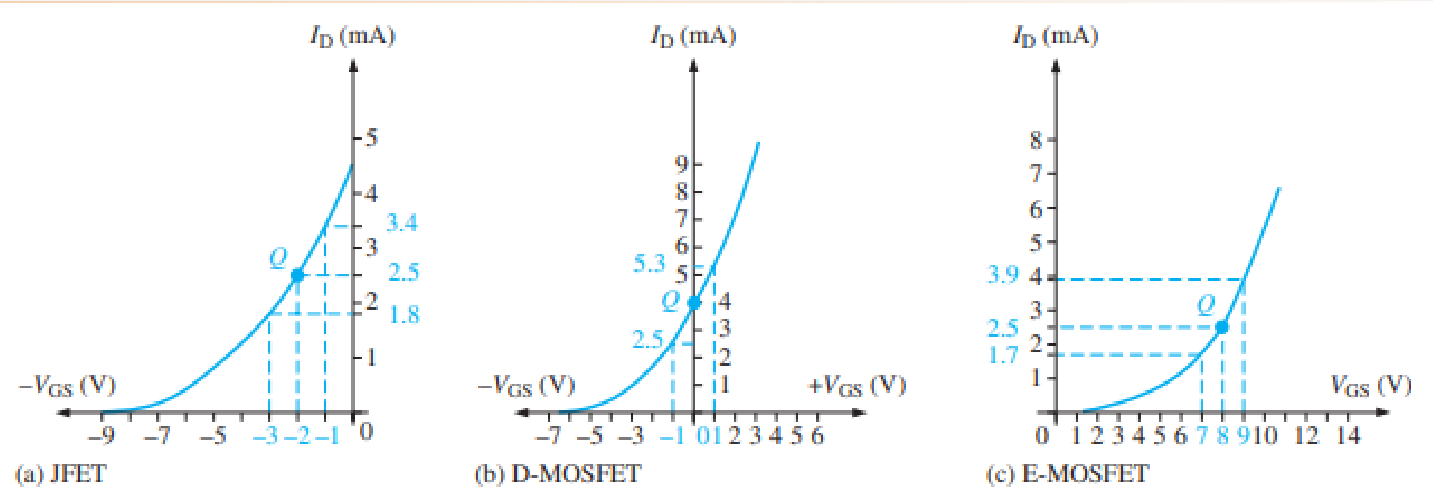


TRANSFER CHARACTERISTIC CURVE JFET, D-MOSFET, E-MOSFET

a) JFET Q-point is at $V_{GS} = -2\ V$ and $I_D = 2.5\ mA$. The peak-to-peak drain current is 1.6 mA.

b) D-MOSFET Q-point is at $V_{GS} = 0\ V$ and $I_D = 4\ mA$. The peak-to-peak drain current is 2.8 mA.

c) E-MOSFET Q-point is at $V_{GS} = +8\ V$ and $I_D = 2.5\ mA$. The peak-to-peak drain current is 2.2 mA.



MOSFET ANALOG SWITCHING

- E-MOSFETs are generally used for switching applications because of their threshold characteristic, $V_{GS(th)}$.
- When the gate-to-source voltage is less than the threshold value, the MOSFET is off.
- When the gate-to-source voltage is greater than the threshold value, the MOSFET is on.
- In the **off** state, when the device is operating at the lower end of the load line and acts like an open switch (very high R_{DS}).
- When V_{GS} is sufficiently greater than $V_{GS(th)}$, the device is operating at the upper end of the load line in the ohmic region and acts like a closed switch (very low R_{DS})

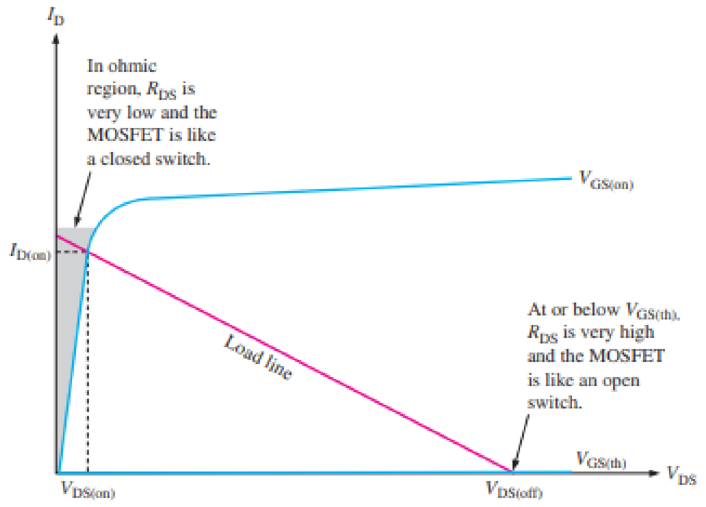


FIGURE 9–32

Switching operation on the load line.

ANALOG SWITCH

- A signal applied to the drain can be switched through to the source by a voltage on the gate.
- A major restriction is that the signal level at the source must not cause the gate-to-source voltage to drop below $V_{GS(th)}$.
- When the MOSFET is turned on, the signal at the drain is connected to the source by a positive V_{GS}.
- When the MOSFET is turned off ($V_{GS} = 0$), the drain signal is disconnected from the source and is equal to zero.

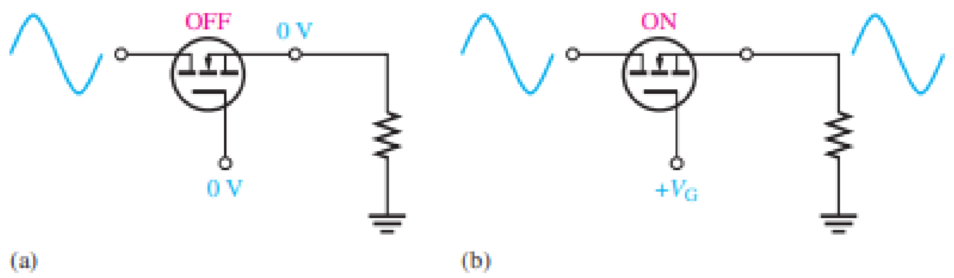


FIGURE 9–34

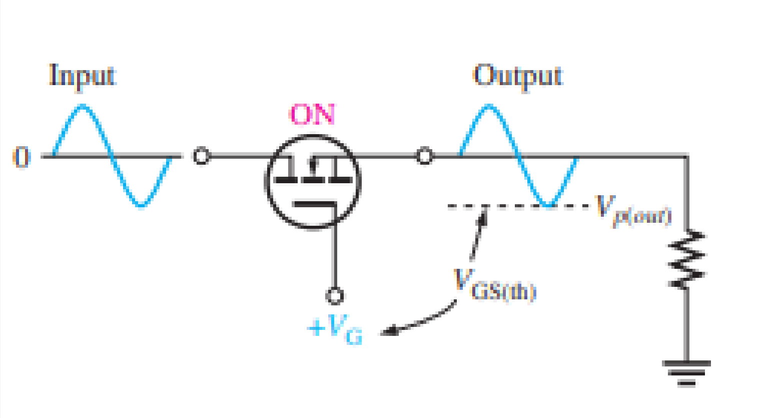
Operation of an *n*-channel MOSFET analog switch.

ANALOG SWITCH

- When the analog switch is on, the minimum gate-to-source voltage occurs at the negative peak of the signal.
- The difference in V_G and $-V_{p(out)}$ is the gate-to-source voltage at the instant of the negative peak and must be equal to or greater than $V_{GS(th)}$ to keep the MOSFET in conduction.

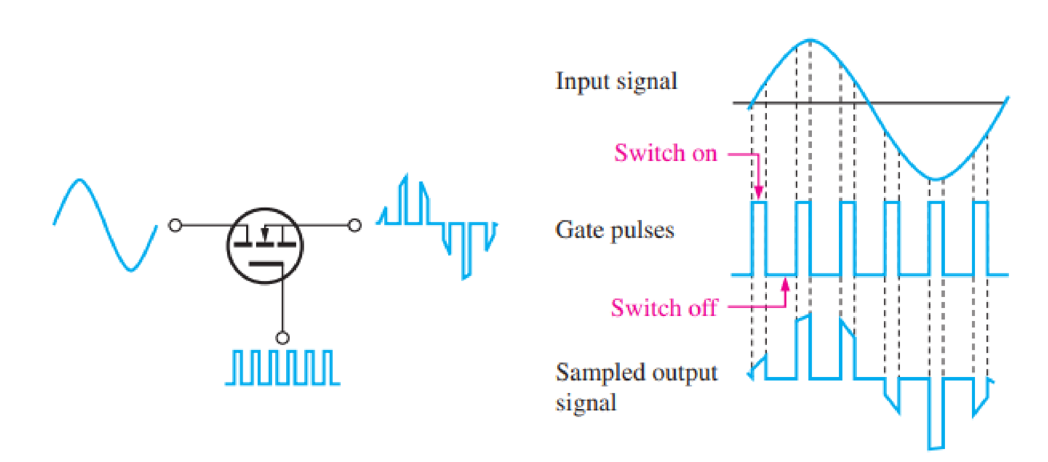
$$V_{GS} = V_G - V_{p(out)} \geq V_{GS(th)}$$

- Output signal amplitude is limited by $V_{GS(th)}$

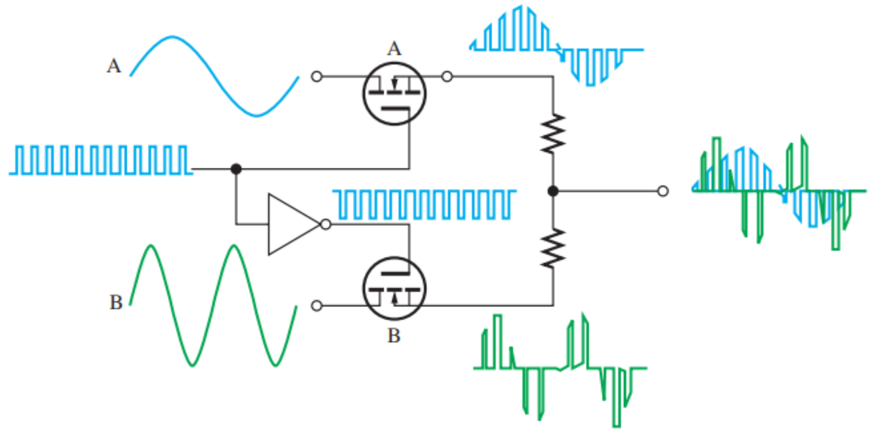


ANALOG SWITCH APPLICATIONS

- Sampling Circuit (Analog-to-Digital Conversion)
  - Sample-and-hold circuit to sample the input signal at a certain rate.
- Analog Multiplexer
  - Where two or more signals are to be routed to the same destination
- Switched-Capacitor Circuit
  - Commonly used in integrated circuit programmable analog devices known as *analog signal processors*.



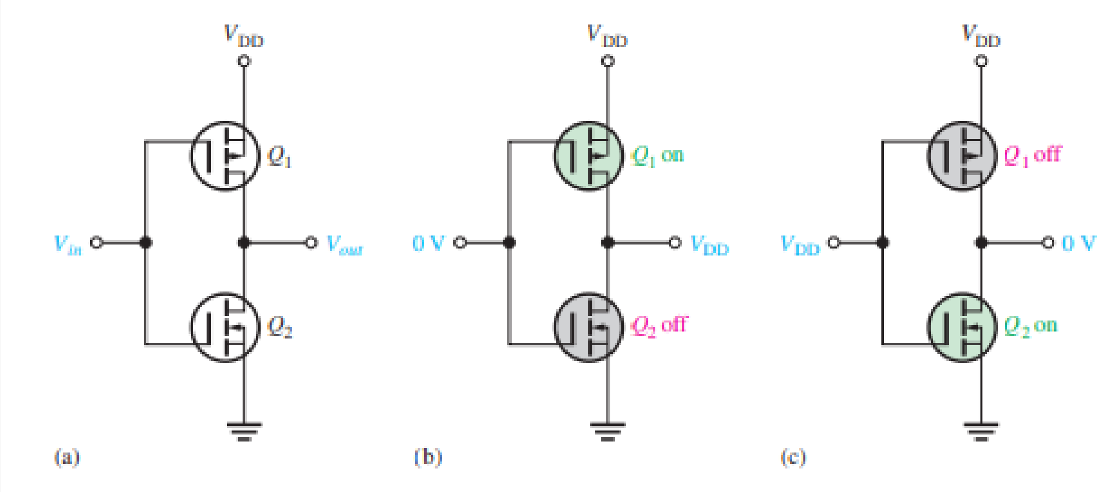
(a) Circuit action (b) Waveform diagram



MOSFET DIGITAL SWITCHING

CMOS (Complementary MOS)

- CMOS combines **n-channel** and **p-channel** E-MOSFETs in a series arrangement.
- The input voltage at the gates is either 0 V or V_{DD}.
- V_{DD} and ground are both connected to source terminals of the transistors.
- When $V_{in} = 0\,V$, Q_1 is **ON** and Q_2 is **OFF**. The output is approximately V_{DD}.
- When $V_{in} = V_{DD}$, Q_2 is **ON** and Q_1 is **OFF**. The output is essentially connected to ground (0 V).



MOSFET DIGITAL SWITCHING

- **Inverter**. When the input is 0 V or low, the output is V_{DD} or high. When the input is V_{DD} or high, the output is 0 V or low. For this reason, this circuit is called an inverter in digital electronics.
- **NAND Gate**. Two additional MOSFETs and a second input are added to the CMOS pair to create a digital circuit known as a NAND gate. Q_4 is connected in parallel with Q_1, and Q_3 is connected in series with Q_2. When both inputs, V_A and V_B, are 0, Q_1 and Q_4 are **ON** while Q_2 and Q_3 are **OFF**, making $V_{out} = V_{DD}$. When both inputs are equal to V_{DD}, Q_1 and Q_4 are **OFF** while Q_2 and Q_3 are **ON**, making $V_{out} = 0$. You can verify that when the inputs are different, one at V_{DD} and the other at 0, the output is equal to V_{DD}.

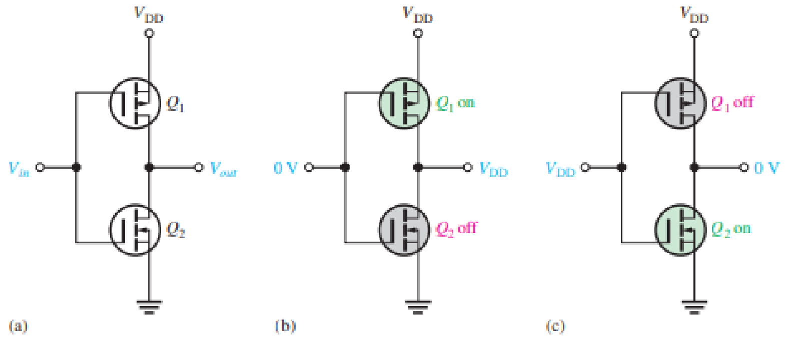
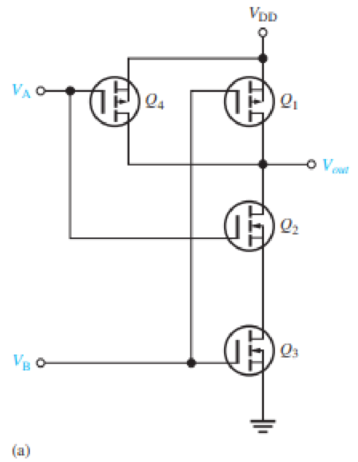


FIGURE 9–41

CMOS inverter operation.

FIGURE 9–42

CMOS NAND gate operation.



V_A	V_B	Q_1	Q_2	Q_3	Q_4	V_{out}
0	0	on	off	off	on	V_{DD}
0	V_{DD}	off	off	off	on	V_{DD}
V_{DD}	0	on	off	off	off	V_{DD}
V_{DD}	V_{DD}	off	on	on	off	0

(b)

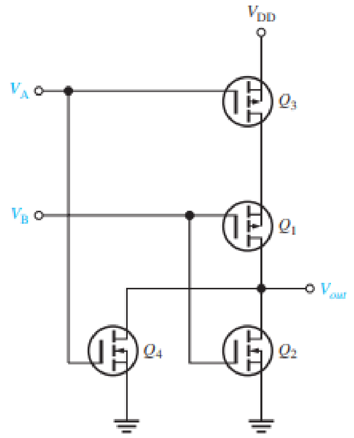
MOSFET DIGITAL SWITCHING

NOR Gate. Two additional MOSFETs and a second input are added to the CMOS pair to create a digital circuit known as a NOR gate. Q_4 is connected in parallel with Q_2, and Q_3 is connected in series with Q_1. When both inputs, V_A and V_B, are 0, Q_1 and Q_3 are on while Q_2 and Q_4 are off, making $V_{out} = V_{DD}$. When both inputs are equal to V_{DD}, Q_1 and Q_3 are off while Q_2 and Q_4 are on, making $V_{out} = 0$. You can verify that when the inputs are different, one at V_{DD} and the other at 0, the output is equal to 0.

To summarize, when V_A **OR** V_B **OR** BOTH are high, the output is low; otherwise, the output is high.

FIGURE 9–43

CMOS NOR gate operation.



(a)

V_A	V_B	Q_1	Q_2	Q_3	Q_4	V_{out}
0	0	on	off	on	off	V_{DD}
0	V_{DD}	off	on	on	off	0
V_{DD}	0	on	off	on	off	0
V_{DD}	V_{DD}	off	on	off	on	0

(b)

MOSFET IN POWER SWITCHING

- The BJT was the only power transistor until the MOSFET was introduced.
- The BJT requires a base current to turn on, has relatively slow turn-off characteristics, and is susceptible to thermal runaway due to a negative temperature coefficient.
- The MOSFET, however, is voltage controlled and has a positive temperature coefficient, which prevents thermal runaway.
- The MOSFET can turn off faster than the BJT, and the low on-state-resistance results in conduction power losses lower than with BJTs.
- Power MOSFETs are used for motor control, dc-to-ac conversion, dc-to-dc conversion, load switching, and other applications that require high current and precise digital control.